Claims

Having thus described our invention, what we claim as new and desire to secure by Letters Patents is:

1. A fault tolerant multichannel communications system having a plurality of communication channels transmitted over a trasmission medium, said communications system comprising:

   (a) a plurality of line cards $1, 2, ..., N$ at each end of a transmission medium, with one of said line cards at each end of said transmission medium for each of said channels and with one of said line cards s at each end of said medium being designated as a spare line card, each said line card having a plurality of local ports, a link port, and a input/output port;

   (b) a plurality of switches with one switch at each end of said medium for each of said line cards, each switch capable for interconnecting a link port of a corresponding one of said line cards to an I/O port or a local port of latter said corresponding one line card, and each switch also capable of interconnecting said I/O port to either said link port or a local port of said corresponding one line card, with a local port of each line card i being hard wired to a local port of line card $i + 1 \bmod N$ and a local port of line card $i - 1 \bmod N$; and

   (c) means for rerouting the I/O of a failed line card f as follows: for each line card i belonging to a set $[s, f)$ of line cards, switching the I/O port of line card $(i + 1) \bmod N$ to a link port of line card i, where $s \neq f$, wherein said failed channel is restored, where said set $[s, f)$ is the set of all line cards such that

$$[s, f) = \begin{cases} \{s, s + 1, ..., f - 1\}, & \text{if } s < f; \\ \{s, s + 1, ..., N - 1, 0, 1, ..., f - 1\}, & \text{if } s > f; \\ \emptyset, & \text{if } s = f. \end{cases}$$

2. A fault tolerant multichannel communications system having a plurality of communication channels, said communications system comprising:

3   (a) a plurality of line cards $1, 2, ..., N$ at each end of said communications medium,

4   with one of said line cards at each end of said medium for each of said channels

5   and with one of said line cards s at each end of said medium being designated as

6   a spare line card, each said line card having a plurality of local ports for a link

7   port, and a input/output port for;

8   (b) a plurality of switches with one switch at each end of said medium for each of said

9   line cards, each switch capable for interconnecting a link port of a corresponding

10   one of said line cards to an I/O port or a local port of latter said corresponding

11   one line card, and each switch also capable of interconnecting said I/O port to

12   either said link port or a local port of said corresponding one line card, with a local

13   port of each line card i being hard wired to a local port of line card $i + 1 \bmod N$

14   and a local port of line card $i - 1 \bmod N$; and

15   (c) means for rerouting a failed line card f as follows:

16   for each line card belonging to a set of line cards $[f, s)$, switching the I/O port of

17   line card i to a link port of line card $(i + 1) \bmod N$, where $s \neq f$ wherein said

18   failed channel is restored, where $[f, s)$ is the set of all line cards such that

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$$[f, s) = \begin{cases} \{f, f+1, ..., f-1\}, & \text{if } f < s; \\ \{f, f+1, ..., N-1, 0, 1, ..., s-1\}, & \text{if } f > s; \\ \emptyset, & \text{if } f = s. \end{cases}$$

1   3. In a multichannel communications system having N channels with line cards 0 through

2       $N - 1$ connected to each end of a transmission medium of said system with each line

3   card having an I/O port, a link port and a plurality of local ports, with one line card

4   connected to each end of said transmission medium for each of said channels, a method

5   of rerouting channels upon detection of a failure of two of said line cards f_0 and f_1,

6   said method comprising:

7   (a) designating two of said line cards as spare line cards s_0 and s_1;

8   (b) hardwiring one of said local ports of each line card $i \bmod N$ to one of said local

9   ports of each line card $(i + 1) \bmod N$ and $(i - 1) \bmod N$;

10   (c) rerouting said failed line cards f_0 and f_1 as follows:

11   i. if $s_0 \leq f_0 \leq f_1 \leq s_1$ then doing spare-to-failed rerouting from s_0 to f_0 and

12   failed-to-spared rerouting from s_1 to f_1, and

13   ii. if $s_0 \leq f_0 \leq s_1 \leq f_1$ then doing spare-to-failed rerouting from s_0 to f_0 and

14   spare-to-failed rerouting from s_1 to f_1,

15   said spare-to-failed rerouting comprising switching each said I/O port of line

16   card $(i+1) \bmod N$ to said link port of line card $i \bmod N$ for all $i \in [s, f)$,

17   where:

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[s, f) = \begin{cases} \{s, s+1, ..., f-1\}, & \text{if } s < f; \\ \{s, s+1, ..., N-1, 0, 1, ..., f-1\}, & \text{if } s > f; \\ \emptyset, & \text{if } s = f, \end{cases}
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and said failed-to-spare rerouting from f to s comprising switching said I/O

port of line card $i \bmod N$ to said link port of line card $(i+1) \bmod N$ for all

$i \in [f, s)$, where:

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[f, s) = \begin{cases} \{f, f+1, ..., f-1\}, & \text{if } f < s; \\ \{f, f+1, ..., N-1, 0, 1, ..., s-1\}, & \text{if } f > s; \\ \emptyset, & \text{if } f = s. \end{cases}
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1   4. A fault tolerant multichannel communication system, comprising:

2   (a) a transmission medium;

3   (b) N line cards 0 through $N-1$, each line card connecting a separate channel to an

4   end of said transmission medium, each line card having an I/O port, a link port,

5   and a plurality of local ports, with two of said line cards s_0 and s_1 being designated

6   as spare line cards, with one of said local ports of each line card $i \bmod N$ being

7   connected to one of said local ports of line card $(i+1) \bmod N$ and line card

8       $(i-1) \bmod N$;

9   (c) A plurality of switches, each of said switches for interconnecting said I/O port,

10   said link port, and said local ports of a corresponding one of said line cards; and

(d) a means for rerouting I/Os from failed line cards f_0 and f_1 using said switches as follows:

    i. if $s_0 \leq f_0 \leq f_1 \leq s_1$ then doing spare-to-failed rerouting from s_0 to f_0 and failed-to-spared rerouting from s_1 to f_1, and

    ii. if $s_0 \leq f_0 \leq s_1 \leq f_1$ then doing spare-to-failed rerouting from s_0 to f_0 and spare-to-failed rerouting from s_1 to f_1,

said spare-to-failed rerouting comprising switching each said I/O port of line card $(i+1) \bmod N$ to said link port of line card $i \bmod N$ for all $i \in [s,f)$, where:

$$[s,f) = \begin{cases} \{s, s+1, ..., f-1\}, & \text{if } s < f; \\ \{s, s+1, ..., N-1, 0, 1, ..., f-1\}, & \text{if } s > f; \\ \emptyset, & \text{if } s = f, \end{cases}$$

and said failed-to-spare rerouting from f to s comprising switching said I/O port of line card $i \bmod N$ to said link port of line card $(i+1) \bmod N$ for all $i \in [f,s)$, where:

$$[f,s) = \begin{cases} \{f, f+1, ..., f-1\}, & \text{if } f < s; \\ \{f, f+1, ..., N-1, 0, 1, ..., s-1\}, & \text{if } f > s; \\ \emptyset, & \text{if } f = s. \end{cases}$$

5. In a multichannel communications system having N channels with line cards 0 through $N-1$ connected to each end of a transmission medium of said system with each line card having an I/O port, a link port and a plurality of local ports, with one line card connected to each end of said transmission medium for each of said channels, a method of rerouting channels upon detection of a failure of one of said line cards, said method comprising:

(a) partitioning said line cards into groups of size at most $k+1$, where each group has at least one spare line card, and where k equals the number of local ports on each line card;

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    (b) for each line card in each of said groups that is not a spare line card, hardwiring one of latter said each line card's local ports to a local port of said one spare line card in said each group; and

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    (c) upon detection of a failure of any of said line cards, rerouting said I/O port of latter said failed line card to the link port of said designated spare line card for the group of line cards containing said failed line card.

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6. In a multichannel communications system having N channels with line cards 0 through $N-1$ connected to each end of a transmission medium of said system with each line card having an I/O port, a bypass port, a link port and a plurality of k local ports where $k < N$, with one line card connected to each end of said transmission medium for each of said channels, a method of rerouting channels upon detection of a failure of one of said line cards, said method comprising:

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    (a) designating one of said line cards as a spare line card s;

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    (b) hard wiring the local ports of each of said line cards such that there is a path from each of said line cards to said spare line card; and

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    (c) rerouting the I/O port of a failed line card by switching said I/O port of said failed line card to its said bypass port which is hard wired to said local port of another one of said line cards and switching said latter local port to said link port of spare line card s.

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7. A fault tolerant multichannel communication system, comprising:

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    (a) a transmission medium;

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    (b) N line cards 0 through $N-1$, each line card connecting a separate channel to an end of said transmission medium, each line card having an I/O port, a bypass port, a link port, and a plurality of k local ports where $k < N$, with one of said line cards being designated as spare line card s, with said local ports of said line cards being hardwired so that there is a path from each of said line cards to line card s;

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(c) A plurality of switches, each of said switches for interconnecting said I/O port, said bypass port, said link port, and said local ports of a corresponding one of said line cards; and

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(d) a means for rerouting I/Os from a failed one of said line cards by using said one of said switches corresponding to said line card to switch said I/O port of said failed line card to its said bypass port which is hardwired to said local port of another one of said line cards and switching said latter local port to said link port of spare line card *s*.

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8. In a multichannel communications system having N channels with line cards 0 through $N - 1$ connected to each end of a transmission medium of said system with each line card having an I/O port, a bypass port, a link port and a plurality of local ports, with one line card connected to each end of said transmission medium for each of said channels, a method of rerouting channels upon detection of a failure of one of said line cards, said method comprising:

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(a) designating one of said line cards as a spare line card;

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(b) hard wiring one of said local ports of each of up to k of said line cards to each of said of said spare line cards, where k is the number of local ports each of said line cards;

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(c) hard wiring said local ports of each of said line cards hard wired to said local ports of said spare line card to an additional $k - 1$ of said line cards;

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(d) repeating step 8c for each line card of said $k - 1$ line cards by hard wiring each of latter said line cards in turn to an additional $k - 1$ of said line cards and so on until all of said line cards form a tree configuration with a plurality of subtrees;

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(e) hard wiring the bypass port of each line card that is a leaf of said tree configuration to the local port of another line card that is a leaf of said tree configuration;

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(f) hard wiring the bypass port of each of said line cards that is not a leaf to the local port of a line card that is a leaf; and

20 (g) rerouting the I/O port of a failed one of said line cards by switching its I/O port
21 to its bypass port and switching appropriate local ports of said line cards so that
22 said I/O port of said failed line card is connected to said link port of said spare
23 line card.

1 9. In a multichannel communications system having N channels with line cards 0 through
2 $N - 1$ connected to each end of a transmission medium of said system with each line
3 card having an I/O port, a bypass port, a link port and a plurality of k local ports
4 where $k < N$, with one line card connected to each end of said transmission medium
5 for each of said channels, a method of rerouting channels upon detection of a failure
6 of two of said line cards, said method comprising:

7 (a) designating two of said line cards as spare line cards s_1 and s_2;

8 (b) hardwiring said local ports of each of said line cards such that for any pair of line
9 cards f_1 and f_2 there are either two paths p_1 from f_1 to s_1 and p_2 from f_2 to s_2
10 where p_1 and p_2 have no common wires, or two paths p_1 from f_1 to s_2 and p_2 from
11 f_2 to s_1 where p_1 and p_2 have no common wires;

12 (c) rerouting the I/O of up to two failed line cards by switching the I/O of said failed
13 line cards to said spare cards by setting switches along paths from said failed line
14 cards to said spares, where said paths have no common wires.

1 10. A fault tolerant multichannel communication system, comprising:

2 (a) a transmission medium;

3 (b) N line cards 0 through $N - 1$, each line card connecting a separate channel to
4 an end of said transmission medium, each line card having an I/O port, a bypass
5 port, a link port, and a plurality of k local ports $k < N$, with two of said line
6 cards being designated as spare line cards s_1 and s_2, with said local ports of said
7 line cards being hardwired such that for any pair of line card f_1 and f_2 there are
8 either two paths p_1 from f_1 to s_1 and p_2 from f_2 to s_2, where p_1 and p_2 have no
9 common wires, or two paths p_1 from f_1 to s_2 and p_2 from f_2 to s_1 where p_1 and
10 p_2 have no common wires;

11 (c) A plurality of switches, each of said switches for interconnecting said I/O port,

12 said bypass port, said link port, and said local ports of a corresponding one of

13 said line cards; and

14 (d) a means for rerouting I/Os from up to two failed line cards by setting said switches

15 along of those of said paths from said failed line cards to said spares. where said

16 paths have no common wires.

1 11. In a multichannel communications system having N channels with line cards 0 through

2 $N - 1$ connected to each end of a transmission medium of said system with each line

3 card having an I/O port, a bypass port, a link port and a plurality of local ports,

4 with one line card connected to each end of said transmission medium for each of said

5 channels, a method of rerouting channels upon detection of failures of up to two of

6 said line cards, said method comprising:

7 (a) designating two of said line cards s_1 and s_2 as spare cards;

8 (b) hardwiring another one of said line cards i to said local ports of s_1 and s_2 to form

9 a dual tree, where i is a leaf card of said dual tree and s_1 and s_2 are internal cards

10 of said dual tree, and said dual tree comprises two trees T_1 and T_2, where s_1 and

11 line card i belong to T_1, and s_2 and line card i belong to T_2;

12 (c) hardwiring another line card x of said line cards to said dual tree according to

13 the following rules:

14 i. if there are two internal cards j and k belonging to T_1 and T_2 respectively,

15 with each of said cards j and k hardwired to each other by less than $k - 1$

16 leaf cards then hardwire local ports of line card x to said local ports of j and

17 k, where x is a leaf card of said trees T_1 and T_2,

18 ii. if rule 11(c)i cannot be applied, and if a single leaf card l is hardwired to two

19 internal cards i_1 and i_2 belonging to T_1 and T_2 respectively, and any other

20 leaf card m hardwired to two internal cards is at least as far as l is from the

21 furthest spare card, then disconnect l from i_1, hardwire a local port of x to a

22 local port of i_1, hardwire a local port of x to a local port of l, where x is now

23   a leaf card belonging to T_1 and l now belongs exclusively to T_2, and

24   iii. if rules 11(c)i and 11(c)ii cannot be applied, and two leaf cards p and q are

25   hardwired to each other, then disconnect p from q, hardwire local ports of x

26   to local ports of p and q, where x is a leaf card belonging to both T_1 and T_2

27   and p and q become internal cards; and

28   (d) rerouting the I/Os of up to two failed line cards f_1 and f_2 by finding the shortest

29   paths $p_{1,1}$ from f_1 to s_1, $p_{1,2}$ from f_1 to s_2, $p_{2,1}$ from f_2 to s_1, and $p_{2,2}$ from f_2 to

30   s_2, choosing q_1 as $p_{1,1}$ and q_2 as $p_{2,2}$ if $p_{1,1}$ and $p_{2,2}$ do not have a common wire,

31   and choosing q_1 as $p_{1,2}$ and q_2 as $p_{2,1}$ otherwise, setting switches along said paths

32   q_1 and q_2 such that said I/Os of said failed line cards are routed to the link ports

33   of said spare line cards.